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Technical Research in Advanced Air Transportation Technologies

Detailed Description for CE-5

En Route Free Maneuvering

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Preface

This report is the first version of a detailed description for the Distributed Air/Ground Traffic Management (DAG-TM) Concept Element (CE) 5, En Route Free Maneuvering. The ideas presented here are preliminary and require additional work, in particular as related to the air traffic control ground concept to support airborne operations.

NASA is soliciting review of this report and welcomes comments. Comments should be sent to:

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1. Introduction

1.1 Background

The Distributed Air/Ground Traffic Management (DAG-TM) concept describes potential modes of operation within the Free Flight concept defined by the RTCA Task Force 3. The goal of DAG-TM is to enhance user flexibility and efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the National Airspace System (NAS).

To explore the DAG-TM concept, the AATT Project formed a DAG-TM Team which met during 1999 and developed a Concept Definition.[1] This document defined 15 DAG-TM "concept elements", covering ATM operations in all phases of flight. The defined phases were:

- Gate-to-Gate (information access and exchange)
- Pre-Flight Planning
- Surface Departure
- Terminal Departure
- En Route
- Terminal Arrival
- Terminal Approach
- Surface Arrival

In 2000, the AATT Project selected an initial set of four concept elements (CEs) to pursue further concept exploration (research) activities.

- CE-5: En Route Free Maneuvering
- CE-6: En Route Trajectory Negotiation
- CE-7: En Route: Collaboration for Mitigating Local TFM Constraints due to Weather, SUA, and Complexity
- CE-11: Terminal Arrival: Self-Spacing for Merging and In-Trail Separation

In May 2000, a DAG-TM Workshop was held at the NASA Ames Research Center to explain to industry the AATT Project's activities and plans for the concept. The workshop focus was on the four initial CEs being developed. Under Task Order 41, a contractor team consisting of System Resources Corporation and Seagull Technology is preparing detailed descriptions of each of the four selected CEs. This document is a detailed description of objectives and operational concepts for CE-5, En Route Free Maneuvering.

1.2 Objectives

This detailed description has the following objectives:

- It provides technical transfer and sharing of information within the NASA research community. It is intended to capture the current thinking of NASA researchers concerning the future ATM environments and capabilities that may be created by this concept.
- It is a guide for a planned program of research in this concept through 2004.
- It is consistent with and amplifies the DAG-TM concept definition.
- It is consistent with AATT objectives as described in the AATT Air Traffic Management Operations Concept (ATM/OPSCON).

- It is a living document intended to be continually updated as the research program progresses, with expected convergence on a feasible and viable concept that provides system-wide benefits.

1.3 Scope

This CE-5 description is intended to provide enough detail to form a basis for further research into the concept. It is not, however, a research plan. The research plan is a separate document being developed by NASA which describes how the concepts presented here will be investigated, and how statements presented here as hypotheses will be tested.

The description has a focus of operational and system requirements, and deliberately avoids design information to the extent possible. The NASA Langley Research Center is in the process of designing automated airborne systems to test the CE-5 concept, including the Autonomous Operations Planner (AOP) which will function on board free maneuvering aircraft. The description is consistent with, and provides additional guidance to, these design efforts.

Finally, specifications are omitted from this document, since capabilities to support the CE-5 concept should evolve as a result of the research to be conducted. To avoid confusion with widely discussed tools such as ADS-B or CPDLC whose specifications are being developed or discussed, this description uses general terms to describe the capabilities necessary to support the concept.

2. Problem Description

This section describes today's problems, followed by a discussion of the root sources of today's problems. The foundation document for the high-level discussion of today's problems below is the AATT Concept Definition for DAG-TM,[1] and the problem statements from that document are taken here as assumptions.

2.1 Today's Problems

In today's en route airspace environment, many aircraft must fly non-optimum routes because of deviations from the user-preferred path. These inefficiencies result mainly from either conflict situations with other traffic or from conformance with local traffic flow management (TFM) constraints. However, often the deviations from the optimum path do not meet user preferences or are excessive. The focus of both CE-5, En Route Free Maneuvering, and CE-6, En Route Trajectory Negotiation, is the investigation of and proposed solution to two of the problems leading to these excessive or non-preferred deviations. As stated in the Concept Definition for DAG-TM:

(a) ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current ATC system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers to allow them to pay less attention to each situation. Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary "resolution" of false alarms (i.e., predicted "conflicts" that would not have materialized had the aircraft continued along their original trajectories). In those cases where a conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and displays), and also to a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user's (flight crew or AOC) trajectory preferences for conformance with local traffic flow management (TFM) constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (flight crew or AOC) is required to submit a request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (airspace congestion, arrival metering/spacing) can result in the flight crew or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences.

Further negotiation between the ATSP and flight crew can adversely impact voice-communication channels and increase workload for both.

2.2 Root Sources of Today's Problems

The above high-level problem descriptions are related, in that they both cause the user to deviate from a user-preferred path. The following characteristics of the present system cause these excessive or unnecessary deviations: trajectory prediction uncertainty, ATSP workload limitations, and lack of user preference knowledge.

2.2.1 Trajectory Prediction Uncertainty

To solve anticipated air traffic conflict situations, future aircraft trajectories must be predicted. The accuracy of these predictions determines the breadth of resolution options available. If trajectory predictions are inaccurate, resolution options involving legal, but closer separation are unavailable. These limitations in resolution options contribute to deviations from user-preferred trajectories. Instead of a user being able to fly a user-preferred trajectory with small deviations for traffic constraints, the user may have to fly a trajectory with much larger deviations to accommodate the uncertainty of the aircraft's trajectory as well as other traffic trajectories.

2.2.1.1 Cause of Trajectory Prediction Uncertainty

Certain characteristics of current air traffic systems are the cause of trajectory prediction uncertainty. The first is that trajectory adjustments made while en route are based on a sector-oriented viewpoint, as opposed to a whole-trajectory viewpoint. This segregation of a trajectory into sector-defined portions means that trajectory adjustments that will be made in future sectors are difficult to predict.

A second cause of uncertainty is the lack of accurate future information about the air traffic environment. First, the actual trajectories followed by aircraft are often not known in the future, because the trajectories will change due to unanticipated conflicts. Second, airspace restriction areas due to weather or congestion are not known accurately because of the dynamic nature of these area hazards. Third, there is imperfect knowledge of wind fields. Fourth, future aircraft intent information is not readily accessible. Within a given sector, a controller can anticipate the resolution maneuvers that will be needed, and, therefore, the intent of the aircraft. However intent information for downstream sectors is not readily accessible, since different controllers are involved in resolutions for these sectors. Lastly, future trajectory predictions are not displayed effectively. Currently, the ATSP has access to a tool that shows a projection of an aircraft's predicted path for a short look-ahead time, but not for an entire trajectory.

2.2.1.2 Effect of Trajectory Prediction Uncertainty

One effect of trajectory prediction uncertainty is the implementation of larger-than-necessary buffers for protected zones around aircraft for separation assurance. Because the future trajectory is uncertain, extra distance is added to the normal protected zones. This extra uncertainty buffer results in a separation well beyond the protected zones as illustrated in Figure 1.

Also, trajectory prediction uncertainty may cause excessive resolution maneuvers. Resolutions are made to avoid not only normal protected zones, but also extra uncertainty buffers. Although these solutions are robust, they also cause maneuvers that may be larger than necessary for legal separation assurance and further deviate a user from the user-preferred path.

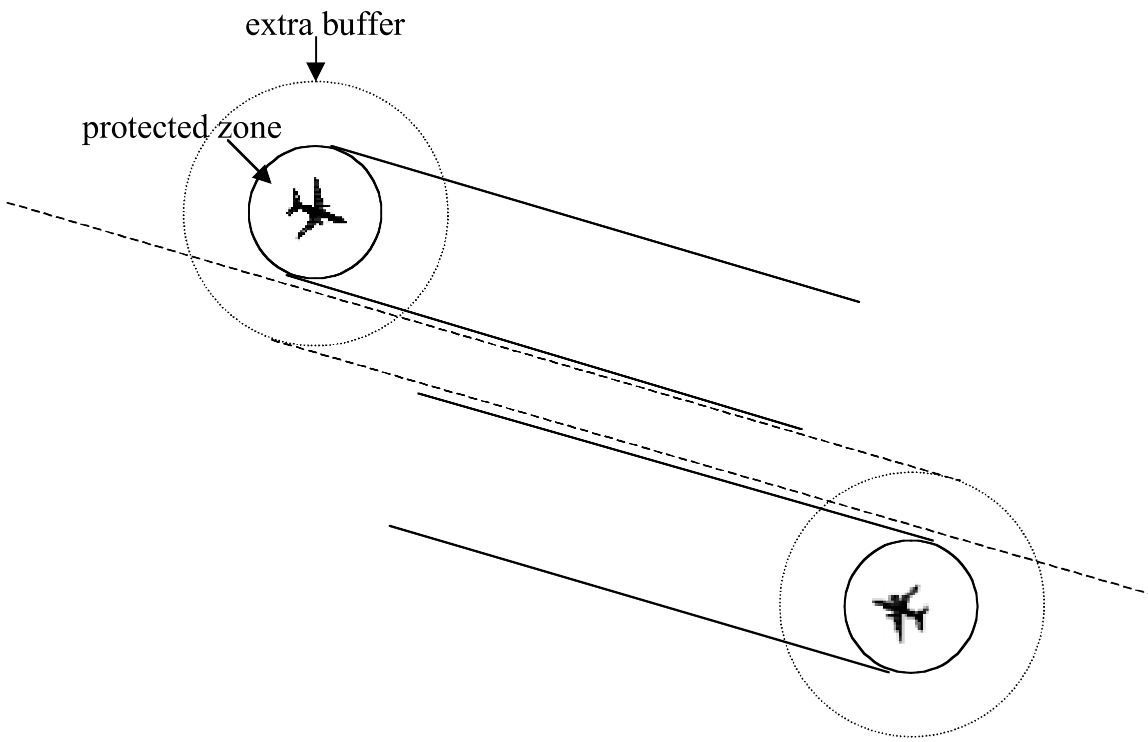

Figure 1. Aircraft Normal Protected Zones and the Effect of Larger Buffer Zones.
(Illustration is not to scale.)

2.2.2 Air Traffic Service Provider (ATSP) Workload Limitations

Currently, the ATSP must provide all separation services necessary for an IFR flight's safety. These tasks include trajectory prediction, conflict detection and resolution, local traffic flow constraint conformance, trajectory adjustments, and flight plan conformance monitoring.

2.2.2.1 Cause of ATSP Workload Limitations

The root cause of ATSP workload limitations is that the ATSP has responsibility for multiple aircraft. Therefore, the ATSP often cannot monitor individual aircraft for long periods of time, and cannot provide individual aircraft the ability to follow user-preferred trajectories. Furthermore, as more aircraft come under the jurisdiction of the ATSP, each aircraft will have less share of the controller's attention. As traffic density increases, the ability to implement user-preferred trajectories decreases.

2.2.2.2 Effect of ATSP Workload Limitations

One effect of ATSP workload limitations is the imposition of larger-than-necessary buffers for protected zones. Because controllers cannot constantly monitor individual aircraft, a buffer is added to the protected zone so that an aircraft is safe until the ATSP has time to revisit the aircraft. These buffer zones have the same effects as the zones caused by trajectory prediction uncertainty described above, and these zones are additive.

Another effect of ATSP workload limitations is a restriction of potential resolution maneuvers that require more monitoring and interaction with the user. The ATSP may select the most easily defined and implemented resolutions, because other, possibly more user-preferred resolutions would require more ATSP monitoring to implement. In the tradeoff of accommodation of user-preferred solutions versus ease of solution implementation, the ATSP must often choose ease of implementation because of workload constraints. In addition, to formulate these in-flight user-preferred resolutions would require more interactions with the user to attain the user preferences. This increased interaction is not possible, since the ATSP also has responsibility for other aircraft.

2.2.3 Lack of User-Preference Knowledge for Resolutions

Flight plans are filed at the beginning of a flight, and often must be changed en route because of conflict situations or adherence to local traffic flow constraints. En-route adjustments to a flight's trajectory are often made without knowledge of user preferences.

2.2.3.1 Cause of Lack of User-Preference Knowledge for Resolutions

The ATSP often must make trajectory adjustments without knowledge of user preferences because no tools facilitate the transfer of this information and the information is difficult to define in a way easily communicated between the flight deck and the ATSP.

2.2.3.2 Effect of Lack of User-Preference Knowledge for Resolutions

The lack of user-preference knowledge means that the ATSP does not take into account this knowledge when creating solutions to traffic problems. Therefore, trajectory changes due to resolution maneuvers may deviate excessively from the user preference, even though a user-preferred resolution exists that solves the traffic problem.

3. Approach

This section first presents an overview of the solution presented by en route free maneuvering to the problems outlined in Section 2. There follows a discussion of how the solution addresses each root source of the problems as described in Section 2. Third is a summary of the benefit mechanisms which motivate research in this concept.

The proposed solutions described below are based upon proposed operational concepts and related research studies.[2,3,4] Their feasibility and potential benefits need to be validated through analysis, simulation and field demonstrations.

3.1 Solution Overview

As stated in the Concept Definition for DAG-TM:

Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local traffic flow management (TFM) constraints.

Free maneuvering aircraft are those that (1) are appropriately equipped, (2) have responsibility for self-separation, and (3) have been granted the authority, capability and procedures needed to execute user-preferred trajectory changes without requesting ATSP clearance to do so. Along with this authority, the flight crew takes on the responsibility to ensure that the trajectory change does not generate near-term conflicts with other aircraft in the vicinity. Free maneuvering aircraft continue to follow defined air traffic rules and procedures as is true of all aircraft.

Free maneuvering will allow aircraft to fly more optimized user-preferred trajectories. Under the CE-5 concept, which takes place in the en route operational domain, flight crews have the authority, tools, and infrastructure necessary to provide their own solutions to traffic conflicts and localized TFM constraints imposed by the ATSP. Such constraints will continue to occur throughout en route airspace; examples are en route metering, miles in trail, and required times of arrival (RTA) in transition.

A user-preferred trajectory modification may be generated by the flight crew, or if time permits it may be created by the AOC and transmitted to the flight crew via datalink. The flight crew instructs the aircraft's flight management system (FMS) to initiate the trajectory, and at the same time on-board automation broadcasts the modified trajectory using automatic dependent surveillance to the ATSP and to other aircraft.

The controller role changes significantly under the CE-5 concept. The controller retains responsibility for all aircraft which are not free maneuvering, called *managed*. The controller uses CD&R decision support tools to maintain separation assurance for managed aircraft, and also to monitor the activities of all aircraft. In the case of a potential conflict between a managed and a free maneuvering aircraft, procedures and flight rules are followed by the free maneuvering aircraft and the controller acting on behalf of the managed aircraft. In order to provide an incentive for aircraft to equip for free maneuvering capability, flight rules include priority status for free maneuvering aircraft in conflicts with managed aircraft.

The traffic management coordinator (TMC) continues to set localized TFM constraints as today. Potential changes in the TMC role are a subject for research.

3.2 Solution Addresses Each Root Problem

The solution of allowing more airborne authority and free maneuvering addresses all of the problems stated in the Problem Description section above.

3.2.1 Free Maneuvering Addresses Trajectory Prediction Uncertainty

One of the causes of trajectory prediction uncertainty is that, once en route, trajectories are viewed in sector-based portions. Under free maneuvering, the flight crew has a trajectory orientation for its own planning and is not restricted by a controller's sector orientation as today. This results in less disruption of the planned trajectory, leading to improved prediction.

Another cause of trajectory prediction uncertainty is the lack of accurate information about the future air traffic environment. Under free maneuvering the flight crew has the information and tools to take a long look ahead on the trajectory toward developing weather and congestion and toward potential conflicts with other aircraft taking into account their intent, and to calculate required maneuvers as early as possible. These activities will reduce uncertainty.

3.2.2 Free Maneuvering Addresses ATSP Workload Limitations

The root cause of ATSP workload limitations affecting user preferences is that the ATSP must take authority for multiple aircraft. Each flight crew of a free maneuvering aircraft has authority for its own trajectory. Therefore, flight crews have the option of following user-preferred routes that were impossible before because the ATSP could not devote enough supervision to a single aircraft.

3.2.3 Free Maneuvering Addresses Lack of User Preference Knowledge for Resolutions

The root cause of lack of user preference knowledge is that the ATSP does not have ready access to the user-preferred knowledge from the flight deck. The free maneuvering aircraft has the ability to respond to many new and unexpected situations during the flight in accordance with preferences.

3.3 Potential Benefit Mechanisms

As part of the concept validation process, benefits will need to be shown. In this section mechanisms for potential benefit are identified, to be proven in the research. If they are proven, benefits of the concept can then be estimated. The following is a list of potential benefit mechanisms from en route free maneuvering, as identified so far:

- An ATM system based on air-ground distributed control better accommodates traffic growth: In today's system, when an aircraft enters an airspace region, more workload is required to accommodate its entry. In the future system, free maneuvering aircraft entering the airspace do not need to be managed by the ATSP.
- Increased user flexibility: The ability to free maneuver increases the number of available and implementable solution options to traffic problems.

- Reduction in excessive and non-preferred deviations: Since free maneuvering users can constantly monitor their own trajectories, these trajectories can be more tailored to user preferences.
- Reduction in buffers: Since a free maneuvering user makes his/her own separation decision by looking down his/her aircraft's trajectory, as opposed to a central controller looking at all the trajectories, buffers can be reduced.
- An ATM system based on air-ground distributed control lowers user costs: Because users are in control of their own trajectories, these trajectories can be more optimized to the user-preferred path. If the user-preferred path is based on flight economics, free maneuvering should lower user operating costs, offsetting capital investment costs.
- Reduced ATSP workload: Because many aircraft will have self-separation capability under free maneuvering, the ATSP can focus more on aircraft that do not have self-separation capability. Therefore, the curve of workload as a function of traffic density will be below that experienced by today's ATC system.
- Increased predictability of RTA conformance: Free maneuvering aircraft have better tools for achieving an RTA, since they can use trajectory orientation to anticipate conflicts well ahead and have a better chance to recalculate conflict-free trajectories that will meet the RTA.
- Increased system safety: Because users need surveillance information for free maneuvering, both users and ATSP have situation awareness. This two-pronged approach provides redundancy in separation assurance.
- Increased global interoperability: Aircraft equipped for free maneuvering can operate in oceanic and international airspace assuming harmonized ATC support.

4. Operational Requirements

The Operational Needs Statements (ONS) which apply to CE-5 are found in the Appendix. These ONS have been created to support the development and ongoing revision of the AATT ATM/OPSCON. CE-5, En Route Free Maneuvering, applies to two different service areas as defined in the AATT ATM/OPSCON. The table lists the ONS addressed by CE-5 first in the Flight Planning service area and then in the Separation Assurance service area.

5. Operational Environment

This section describes the assumptions behind development of the concept description for en route free maneuvering, the current and future conditions under which this concept will be applied, the baseline ATC situation and what changes may have to occur to support this concept, and different environments in which the problem and solution may take different forms. The section has four subsections as follows:

- airspace structure and constraints
- traffic mix and equipage
- CNS infrastructure
- ATM environment

5.1 Airspace Structure and Constraints

En route free maneuvering is designed for domestic en-route airspace, although many aspects of the concept element could apply to low-density terminal departure and arrival domains, as well as oceanic and international airspace. It will need to operate in unconstrained, constrained, and transition airspace. Unconstrained airspace is a situation where free maneuvering aircraft need make no trajectory adjustments away from user-preferred trajectories except for separation assurance. Constrained airspace includes the following kinds of constraints on user trajectories:

- TFM initiatives
  - traffic volume restrictions
  - flow rate assignments
- area hazards
  - weather
  - SUA

Transition airspace is that portion of en-route airspace immediately outside terminal airspace, within which arriving aircraft are conducting significant descents to their arrival routes and departing aircraft are conducting significant climbs to cruise.

The CE-5 concept does not address strategic traffic management and negotiations concerning constrained airspace, which is the subject of CE-7.

It is assumed that a route structure may exist in the CE-5 environment, along with a system of named waypoints. The latter are used for easy communication of locations. However, free maneuvering aircraft are no longer required to follow the routes. These aircraft may also perform cruise climbs and do not need to adhere to cardinal altitude rules.

Research will determine a set of feasible procedures for ATC to direct "managed" aircraft, including the use of cardinal altitudes and fixed route structures. Initially, it is assumed that managed aircraft follow current cardinal altitude standards and fixed route structures.

The concept of "managed only" airspace may be brought into CE-5. In this airspace, aircraft may only operate if they are managed.

5.2 Traffic Mix and Equipage

There are two types of aircraft: free maneuvering and managed. Free maneuvering aircraft have automation enabling situation awareness, self-separation, and trajectory re-planning. These aircraft have the authority to make trajectory changes with the restriction that no new conflicts be created within a defined period of time (e.g., 8 minutes) by their maneuvers. The appropriate time horizon is a subject of research. They must transmit their position and intent to enable conflict detection and resolution by other free maneuvering aircraft and the ATSP.

Free maneuvering aircraft voluntarily equip themselves for self-separation and trajectory re-planning and, by doing so, achieve the benefits while assuming additional responsibilities. These aircraft have the baseline equipage requirements for today's en route airspace. Required additional equipage includes:

- flight management system
- datalink
- interactive, multifunctional cockpit display
- automatic dependent surveillance
- decision support
  - conflict detection and resolution (CD&R)
  - trajectory re-planning
- Traffic Alert and Collision Avoidance System (TCAS)

All types of aircraft (e.g., air carrier, general aviation, corporate and military) may be free maneuvering. The concept allows, but does not require, association with an AOC. Global interoperability will be a design goal for the free maneuvering aircraft capability.

Managed aircraft continue to be controlled by ATC in a manner similar to today. The concept of managed aircraft equipage is still evolving. In addition to the requirements for today's en route airspace, managed aircraft of the future may choose to obtain some of the equipage that will be required for free maneuvering aircraft, in order to achieve benefits such as increased situation awareness and improved data communications.

5.3 CNS Infrastructure

Datalink is the principal addition to today's communications infrastructure. There are two kinds of ground to air datalink: addressed, for specific constraints, and broadcast, for messages of general interest. Addressed datalink messages to free maneuvering aircraft include controller advisories and traffic management directives for the aircraft, such as commitment to an RTA. Broadcast messages include weather and SUA advisories. Air to ground datalink will be used for pilot acknowledgements.

The Global Positioning System (GPS) is certified for en route navigation. For surveillance to operate effectively, a free maneuvering aircraft must know its own state with significant accuracy including its position which is obtained by reading from a GPS receiver. This state (including position and velocity) and the aircraft's intent must be broadcast regularly via automatic dependent surveillance. Requirements for this broadcast are further described in Section 6.

The surveillance broadcast needs to be received by nearby free maneuvering aircraft and also by the ATSP on the ground. This information along with comparable information on managed aircraft is broadcast ground-to-air as traffic information to all free maneuvering aircraft in that region.

5.4 ATM Environment

An advanced decision support system, operating in conjunction with the controller display, is essential for the controller. This will provide a high level of situation awareness, along with a CD&R capability to anticipate conflicts and to implement conflict-free resolutions as required. For the controller to have the most current aircraft intent information as part of decision support, the ATSP automation must have a data fusion capability which includes radar, Host flight plan, and aircraft state and intent information from aircraft broadcast.

The CE-5 concept does not require any change in strategic traffic management, although changes as a result of CE-5 may be beneficial. Further research is needed to demonstrate whether changes in local traffic management, either in automation or procedures or both, are required or beneficial.

6. Operational Characteristics

The discussion of operational characteristics for CE-5, en route free maneuvering, starts with general considerations which include all actors. This is followed by subsections addressing characteristics from the perspective of the ATSP, the pilot, and the AOC respectively.

In order to implement free maneuvering, several system capabilities are necessary. First, information exchange among all actors must be expanded. CE-5 relies on DAG-TM CE-0, Information Access/Exchange for Enhanced Decision Support, to define the required information. For flight deck situation awareness this includes:

- state and intent information about other aircraft
- current and predicted NAS constraint information (delays, flow initiatives, SUA status)
- 4D weather information (winds, temperature, turbulence, storm cells, icing, etc.)
- real-time pilot reports from aircraft maneuvering near weather-impacted areas

This information comes directly from the ground infrastructure or from other aircraft.

Second, new automation is necessary for both the flight deck and ATC. The flight deck needs automation to process the incoming information for situation awareness, and to assist in the creation of valid, optimized trajectories based on that incoming information. ATC automation also needs to be enhanced for situation awareness, including awareness of free maneuvering aircraft.

Third, the roles and responsibilities of flight crews and the ATSP must be established. Currently, trajectory change authority resides only with the ATSP. Under free maneuvering conditions, either the flight crew or the ATSP may have authority, depending on the situation. Also, free maneuvering aircraft must be integrated with managed aircraft. The capability for this meshing of ground and airborne traffic management must be achieved for free maneuvering to be successful.

Concept Element 5 attempts to meet the above requirements by distributing responsibility between flight crews and controllers as a function of time to point of closest approach, as presented in Figure 2.[5] Several temporal zones are defined, based on the concept that user and controller goals, and hence their resolution strategies, change as a function of time to the point of closest approach. The sizes, relative locations, and characteristics of these zones will be subjects of research.

For conflicts detected while in the non-coordinated resolution zone, appropriately equipped aircraft have the opportunity to resolve the conflict without participation by the controller. Aircraft state information, such as position and altitude, and intent information, such as upcoming trajectory-change points, are broadcast from each aircraft. Based on these data as well as knowledge of goals, performance, and the environment, airborne decision support automation provides the crews with specific maneuver advisories. Non-coordinated resolutions are based entirely on the flight management goals of the participants. One aircraft may provide the entire resolution maneuver or several aircraft may maneuver partially. Custom airborne CD&R algorithms may be used, and resolutions take place either by direct negotiation or by each crew observing the actions of the other.

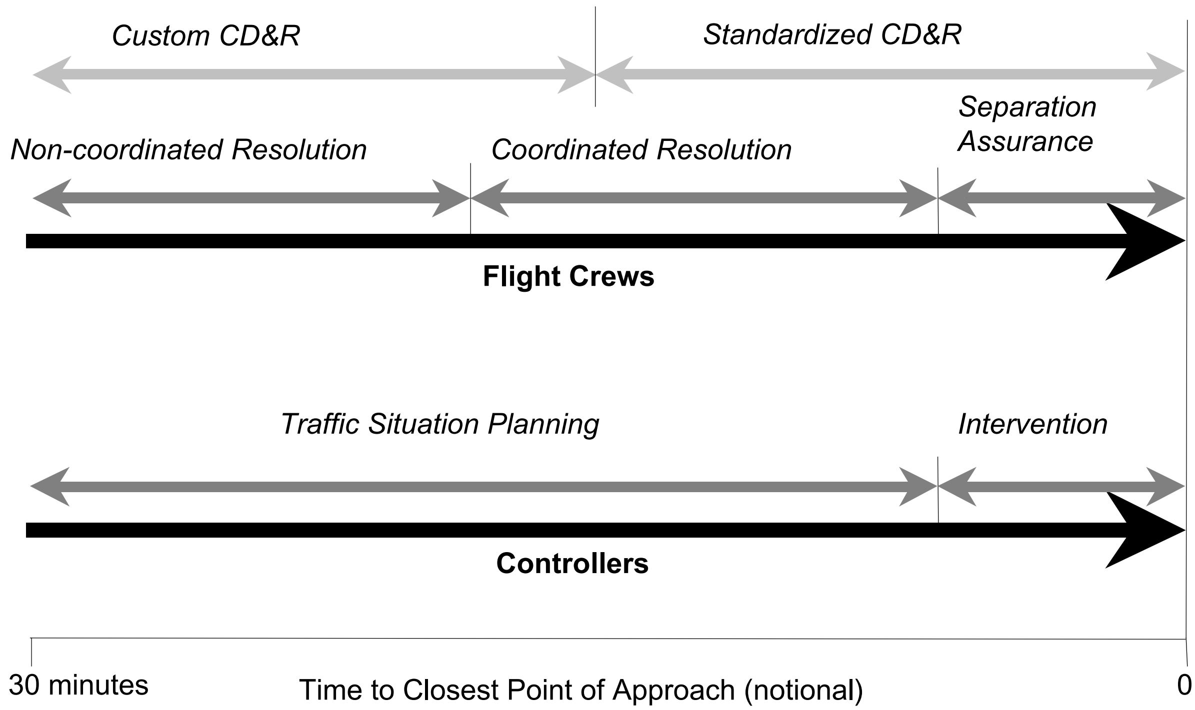

Figure 2. Flight crew and controller temporal zones

Concurrently, controllers are in the traffic situation planning zone and use decision support automation to maintain awareness of the traffic situation. With this awareness, they may predict future regions of traffic complexity too great to enable safe intervention. One measure of traffic complexity may be the number of conflicts predicted to occur in a region. Controller automation provides advisories to reroute some aircraft away from a predicted high-complexity region, or if found necessary for concept feasibility, advises controllers to cancel autonomous maneuvering authority for some or all aircraft.

If flight crews do not resolve the conflict within the time defined by the non-coordinated resolution zone, they enter a coordinated resolution zone. At such a point aircraft are required to follow predetermined rules for resolving a conflict. The rules dictate which aircraft must maneuver and/or the maneuver degrees of freedom. They may be based on extensions of visual flight rules. If the time to separation violation continues to decrease beyond a specified threshold, all aircraft may be required to use identical conflict detection and resolution algorithms. Assuming each flight crew has identical information, the advisories provided to each are compatible. For these situations, crew goals and maneuver efficiency are secondary to safe conflict resolution.

An important goal for airborne separation assurance within the DAG-TM concept of operations is to resolve conflicts before a controller needs to intervene. However, if the aircraft do not achieve a conflict resolution, they will enter the controller's intervention zone. Within the zone, whether the controller has the responsibility to intervene or just the option to intervene will be a subject of research. By intervening, the controller assumes responsibility for separation assurance and exercises positive control. The size of the zone is based on look-ahead practices and comfort levels of controllers. The controller is provided ground-based automation to assist in intervening and resolving the conflict by issuing clearances for one or more aircraft to maneuver. Concept feasibility depends on the intervention zone being a reasonable size.

The flight crew's separation assurance zone corresponds to the controller's intervention zone, as shown in Figure 2. Airborne separation capability should be used to maximize safety in this zone, even though the controller may have responsibility for separation assurance. In the separation assurance zone, crew goals, maneuver efficiency, and passenger comfort are secondary to safe conflict resolution or collision avoidance. To minimize the number of missed alerts, conflict detection may be based on aircraft state information only.

A zone not shown in the diagram is the TCAS zone. We may assume that all free maneuvering aircraft are equipped with TCAS, which provides an independent alert and a resolution advisory to a conflict occurring in less than about 40 seconds.[6]

An initial estimate for the initiation of the coordinated resolution zone is 15 minutes before closest approach; and initiation of the separation assurance/intervention zones, 5 minutes. Research will further explore and validate/adjust these time horizon estimates.

There are a number of assumptions which follow from the distributed responsibility concept. First, controllers' interaction with free maneuvering aircraft normally consists of advisories and traffic management directives, such as the need to meet an RTA or to avoid areas of traffic saturation. Second, a free maneuvering aircraft may make trajectory changes without restriction, with the exception that it shall not make a maneuver which creates a new conflict with any aircraft (free maneuvering or managed) within a defined period of time (e.g., 8 minutes). Third, free maneuvering aircraft need automatic surveillance broadcasts from other free maneuvering aircraft for adequate situation awareness. These broadcasts should include state and intent and occur at a frequency of about 1 per second. Fourth, to complete situation awareness free maneuvering aircraft need to receive traffic information broadcast from the ground which include equivalent data on managed aircraft. These broadcasts may be constrained to every 12 seconds due to the radar update rate. Fifth, surveillance broadcasts need to be received by the ground and integrated into ground automation to provide controllers an equal situation awareness to that of free maneuvering aircraft, with a concurrent CD&R process. The CD&R systems in air and ground are equivalent in capability but are not necessarily built to the same design.

6.1 ATSP View

The principal interfaces between the controller and free maneuvering aircraft are the issuance of traffic management directives, including RTAs, for traffic management purposes; and potential communications within the intervention zone, to be determined by research. The traffic management conditions may exist both in en route cruise and in transition. In developing an RTA, first an ETA is given by the flight crew. Second, a soft RTA is negotiated between ATSP and flight crew at a time X minutes ahead of reaching the fix, where X is currently assumed 30 minutes for research purposes. Third, a frozen RTA is set to which the flight crew must commit.

If a free maneuvering aircraft misses an RTA, the re-planning responsibility is shared. The service provider will find a gap for aircraft re-sequencing, provide a new RTA, and the aircraft will replan its trajectory to meet it.

The controller monitors all aircraft, both managed and free maneuvering, in his or her sector. Monitoring conflicts which do not involve managed aircraft is a secondary workload requirement similar to today's VFR flight following. ATSP automation will monitor whether free maneuvering aircraft are conforming to their broadcast intent and may notify the controller when there are deviations. The controller may issue conflict advisories and path deviation advisories to free maneuvering aircraft, especially in cases of conflicts between managed and free maneuvering aircraft.

6.2 Pilot View

The flight crew of a free maneuvering aircraft has responsibility for the following functions: situation awareness, self-separation assurance, flight re-planning, and adherence to constraints issued by the ATSP. The last function has been discussed above and is not further addressed here. The capabilities described in the following are considered to be minimum requirements for free maneuvering aircraft, subject to further research.

6.2.1 Situation Awareness

The free maneuvering aircraft has an interactive navigation display which shows weather and traffic data to a distance which will be determined as the concept further matures. Traffic needs to be viewed at least 30 minutes ahead for conflict detection, and weather much farther out for aid in long-range CD&R. Weather information would be best viewed on a second display with a greatly expanded range.

Airborne weather information is integrated based on ground information and on-board weather systems. Information is required on winds, turbulence and convective weather. It is expected that gridded 4-D weather and wind products are available. These may start from centralized sources, then become individually tailored for the flight deck depending on the pilot's weather service provider.

In order for a given free maneuvering aircraft to have situation awareness of other free maneuvering aircraft, each must broadcast its state and intent, with the intent preferably as a 4-D trajectory. The required broadcast radius will be determined through research. Initially, 120 nautical miles is assumed. A traffic information broadcast from the ground provides completeness by showing state and intent of all managed aircraft and free maneuvering aircraft beyond the air-to-air broadcast radius. Flight deck automation merges this information to display traffic out to 600 nautical miles from the aircraft.

6.2.2 Self-Separation Assurance

The discussion of self-separation assurance by free maneuvering aircraft is divided into four highly interrelated topics: trajectories, CD&R, flight rules, and issues concerning intent.

Trajectories

To aid in designing separation assurance capabilities, a number of different trajectories are first defined for the purposes of conflict detection and resolution. There are five trajectories for a subject free maneuvering aircraft. These are:

- state-projection trajectory. This is an extrapolation of current position, speed and heading.
- intent trajectories
  - commanded trajectory - the route the aircraft's flight management system (FMS) actually flies given autoflight commands and aircraft performance constraints, and assuming no more pilot inputs.
  - planning trajectory – best prediction of what the aircraft shall do given all "known intent".
  - provisional trajectories – alternative routes tested for hazards using the planning trajectory method.
  - inferred intent trajectory – modification to the planning trajectory when the aircraft is not maneuvering consistent with "known intent".

There are three trajectories for surrounding traffic, called the intruder. These are:

- state-projection trajectory.
- estimated intent trajectory – based on intruder trajectory broadcast if available, and traffic processing functions (ambiguity resolution, data confidence, data fusion).
- inferred intent trajectories – possible trajectories for the intruder when estimated intent fails to produce a deterministic result.

Conflict Detection and Resolution

Each free maneuvering aircraft has a CD&R decision support tool which provides the flight crew a conflict alert with an airspace hazard or intruder traffic well ahead of the conflict. Given trajectory prediction accuracy considerations, it is estimated that reliable alerts could be provided about 30 minutes ahead, to be confirmed by research. One or more resolution trajectories are also provided. The CD&R tool utilizes traffic, winds and area hazards in calculating conflict alerts and conflict-free resolution trajectories. Traffic constraints and RTAs are also used to constrain the resolutions. Conflict alerts and resolutions are shown on the flight deck's interactive navigation display, as an addition to the flight crew's situation awareness.

For conflicts within the standardized CD&R zone or closer, the CD&R tools on different aircraft must use the same algorithm so that if two conflicting aircraft both maneuver, they will move away from each other. For conflicts within the TCAS zone, TCAS will take precedence.

It is a hypothesis that a free maneuvering aircraft can perform adequate trajectory prediction of an intruder to perform CD&R, without having detailed knowledge of the intruder's performance characteristics. This comes into play in transition when most aircraft are performing climbs and descents, and the speeds and altitude change rates differ greatly among different aircraft types.

The initial estimate, to be confirmed by research, is that to fulfill CD&R requirements a free maneuvering aircraft should broadcast its intent forward through the next two trajectory change points (TCPs).

A free maneuvering aircraft should check its entire en route flight plan for airspace conflicts, but only 30 minutes ahead for conflicts with other aircraft due to expected trajectory prediction uncertainties.

Flight Rules

Flight rules provide the means for procedural conflict resolution. They specify for particular conflict situations who has lower priority (i.e., who deviates) and what restrictions exist on maneuvering (i.e., how they deviate).

Simple flight rules that are easily recollected and interpreted are preferred to more complicated rules. The optimal level of complexity is a research question, involving tradeoffs among flexibility of maneuver, predictability of maneuver, and separation assurance.

If a free maneuvering and a managed aircraft are in conflict, the baseline concept gives the free maneuvering the right of way. The free maneuvering aircraft may not, however, create a near-term conflict by changing intent.

Intent

A controller assures separation for managed aircraft in the same way that pilots of free maneuvering aircraft assure separation for themselves. In either case, the responsible party may conduct tactical maneuvers for safety reasons. There will be situations where a free maneuvering aircraft makes tactical moves for safety, thereby having its intent uncertain to the controller. There will be situations where a controller directs a managed aircraft to make tactical moves for safety, thereby having its intent uncertain to nearby free maneuvering aircraft. This is true even though the aircraft's motion will be broadcast in both cases and will be received by the other party. There still are questions – will that aircraft continue on its current heading? It's turning – how far will the turn go before it straightens out? Will it turn back, and when?

Robust decision support systems are available both to the controller and to pilots of free maneuvering aircraft to handle situations of uncertain intent. In addition, the controller may issue an advisory (datalink or voice) to the free maneuvering aircraft in cases of controller action but this is subject to workload.

6.2.3 Flight Re-Planning

The free maneuvering aircraft has the following restrictions on the flight re-planning function. The aircraft must be able to satisfy separation constraints, avoid traffic and area hazards, operate in a 30-minute look-ahead period for aircraft-to-aircraft conflicts, operate within aircraft performance limitations, and satisfy user preferences to the extent possible. It must be able to re-plan to meet RTAs imposed by ATC. It must broadcast new trajectories resulting from new plans. The aircraft is supposed to adhere accurately to its planned trajectory in the absence of disturbances. There may be a penalty for a flight crew not adhering to its broadcast trajectory.

Re-planning may be strategic or tactical. Strategic re-planning is performed by determining a complete solution to one or more problems or constraints, such as hazards or RTAs, prior to executing the solution. Tactical re-planning is performed by selecting and executing a maneuver to avoid a problem before a complete solution is available, with the understanding that additional maneuvers may be required “on the fly”, as the traffic situation develops.

6.3 AOC View

The AOC interaction with the flight deck or the ATSP is not a central part of the CE-5 detailed concept. For air carrier aircraft, the AOC transmits company constraints to the flight deck as a factor in flight planning and re-planning. Given enough time, the pilot may consult with the AOC and request advice on flight plan changes. The AOC may communicate with traffic management for collaborative decisions which will satisfy traffic flow constraints. All of this activity may influence the ATSP and flight crew actions, and is part of the larger DAG concept, but is behind the scenes as far as examining and implementing en route free maneuvering is concerned.

7. NAS Functional Impacts

This section discusses the NAS impacts, including planned NAS architecture components, of the concept as described. Section 7.1 describes functional requirements, and section 7.2 shows the functional design which derives from these requirements.

7.1 Functional Requirements

The following functional changes from the current NAS, expressed in terms of technology and infrastructure, are needed to support the concept. These are described in the areas of Communications, Navigation, Surveillance, Automation, Weather and Traffic Management.

7.1.1 Communications

CE-5 relies on DAG-TM CE-0, Information Access/Exchange for Enhanced Decision Support, to define required communications. These include the following. Ground-to-air communications with free maneuvering aircraft are both by datalink and voice. Datalink communications are both broadcast and addressed. The ATSP broadcasts advisories on SUAs, congested areas, flow constraints and weather, and provides detailed traffic information to be utilized by the flight deck's decision support tools. Aircraft-specific advisories and flow constraints such as RTAs are sent by addressed datalink. Voice communication may be used for this latter function but on an exception basis.

Weather service providers send winds and weather, probably as gridded products, via addressed datalink. These products are tailored to the aircraft position and user planning requirements. AOC-flight deck communication is facilitated by use of company addressed datalink.

Air-to-ground communications from free maneuvering aircraft are by addressed datalink and voice. Addressed messages include negotiations concerning flow constraints, message received, and accept/reject action. Voice communication may be used for these purposes but by exception.

Air-to-air addressed communications between free maneuvering aircraft may occur during aircraft-aircraft conflicts in the non-coordinated resolution zone. In addition, free maneuvering aircraft issue surveillance broadcasts, discussed in 7.1.3.

There is no change in managed aircraft communications except that if the managed aircraft has datalink, controllers may send directives via addressed datalink. The air-ground messages would include message received, and accept/reject.

7.1.2 Navigation

There are no new functional navigation requirements imposed on the service provider by the CE-5 concept. The GPS is assumed certified as a means of navigation and is relied on as part of the aircraft's state information and to check its trajectory adherence accuracy.

The free maneuvering aircraft must have an advanced flight management system (FMS) capable of adhering to a planned 4D (i.e., position, altitude, and time) trajectory to a specified Required Navigation Performance (RNP) level, to be determined by research.

7.1.3 Surveillance

Free maneuvering aircraft must broadcast information for surveillance purposes based on the aircraft's trajectory data calculated by its FMS. It broadcasts state and intent data, with state data at 1 second intervals and intent data every nth broadcast, where the value of n is a research question. How much information is required in the intent messages, namely level of detail and time period, will be determined by research. The initial assumption is two trajectory change points, or enough TCP's to cover 30 minutes, whichever is greater.

The service provider must receive these broadcasts from free maneuvering aircraft and perform data fusion with radar surveillance information and Host flight plan data. This process creates a comprehensive picture of traffic state and intent including both free maneuvering and managed aircraft. This traffic information is broadcast for reception by free maneuvering aircraft to provide them with about a 600 mile (30 minute) traffic situation awareness.

7.1.4 Automation

Free maneuvering aircraft must have the following automation capabilities:

- collect and process intruder aircraft data
- collect and process area hazard data
- develop knowledge of state and intent of itself and intruder traffic
- perform CD&R, meeting multiple simultaneous airspace and traffic management constraints
- perform trajectory re-planning
- accept user preferences
- provide interactive navigation display for flight crew situation awareness and alerting
- prioritize constraints, including managing over-determined situations, namely where there is no conflict resolution which satisfies all constraints

The service provider needs to develop an increased surveillance data fusion capability as described above for the purpose of providing the controller with a good decision support capability. Specific requirements for controller decision support and displays for the CE-5 concept need to be further developed.

7.1.5 Weather

Improved wind and weather models and information distribution are needed for free maneuvering aircraft to accurately plan and fly their trajectories. Accurate winds are needed for proper functioning of the CD&R routines.

The same scope and detail of weather information is available to the ATSP as to the free maneuvering flight crews. It is important that the data set be common to all users and the ATSP, so that during coordinated conflict resolution the different actors will perform as expected.

7.1.6 Traffic Management

There are no changes required for national traffic management, that is at the Command Center level. The CE-5 concept can utilize traffic management directives in whatever form they may take. However, improvement in collaboration between the TMC and the flight crew, and use of the 4D flight object, would enable real-time user preferences to be incorporated into traffic management constraints.

7.2 Functional Design

Figure 3 is a functional design diagram showing those NAS systems and services which are essential for supporting the CE-5 concept. Current and future air traffic systems and services which are general to air traffic control but not specifically utilized in CE-5 are not shown.

The two aircraft shown are free maneuvering. Each maintains accurate position information and trajectory conformance using GPS as an input to the flight management system (FMS). Each free maneuvering aircraft broadcasts surveillance information to other free maneuvering aircraft and to a ground receiver which transmits this to ATC automation. The ATSP makes use of secondary (beacon) surveillance which determines position, altitude and other information from both free maneuvering and managed aircraft.

Within each en route center, dependent and direct surveillance information are combined with flight object information from the Host in a data fusion routine, presenting accurate information to each sector controller on all flights. A decision support tool supplements this with essential CD&R information.

Traffic information from the data fusion process is broadcast via datalink for use by free maneuvering aircraft, to provide a complete situation awareness of intruder traffic including both free maneuvering and managed. Two additional broadcasts add to the free maneuvering aircraft's situation awareness. One is the ATSP's flight information services including traffic management advisories and SUA status. The other is a gridded array of aviation weather and winds from a weather service provider, which in turn is based on FAA, NOAA and private data sources. Each weather service provider may furnish weather products tailored to its subscribers.

In addition to the FMS, the free maneuvering aircraft automation includes an interactive display and the AOP, which furnishes the pilot with essential decision support concerning CD&R and trajectory planning.

The controller and pilot exchange addressed messages via datalink. These messages include advisories and traffic management directives, as discussed previously.